Light-Induced Metastability in Hydrogenated Nanocrystalline Silicon Solar cells

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Outline

1. Review of the results reported in the last team meeting

   (a) spectral dependence of light-induced degradation in nc-Si:H solar cells

2. New experimental results-Electrical bias dependence

   (a) Forward current injection

   (b) Light-soaking under reverse bias

3. Microscopic Model for the metastability in nc-Si:H solar cells

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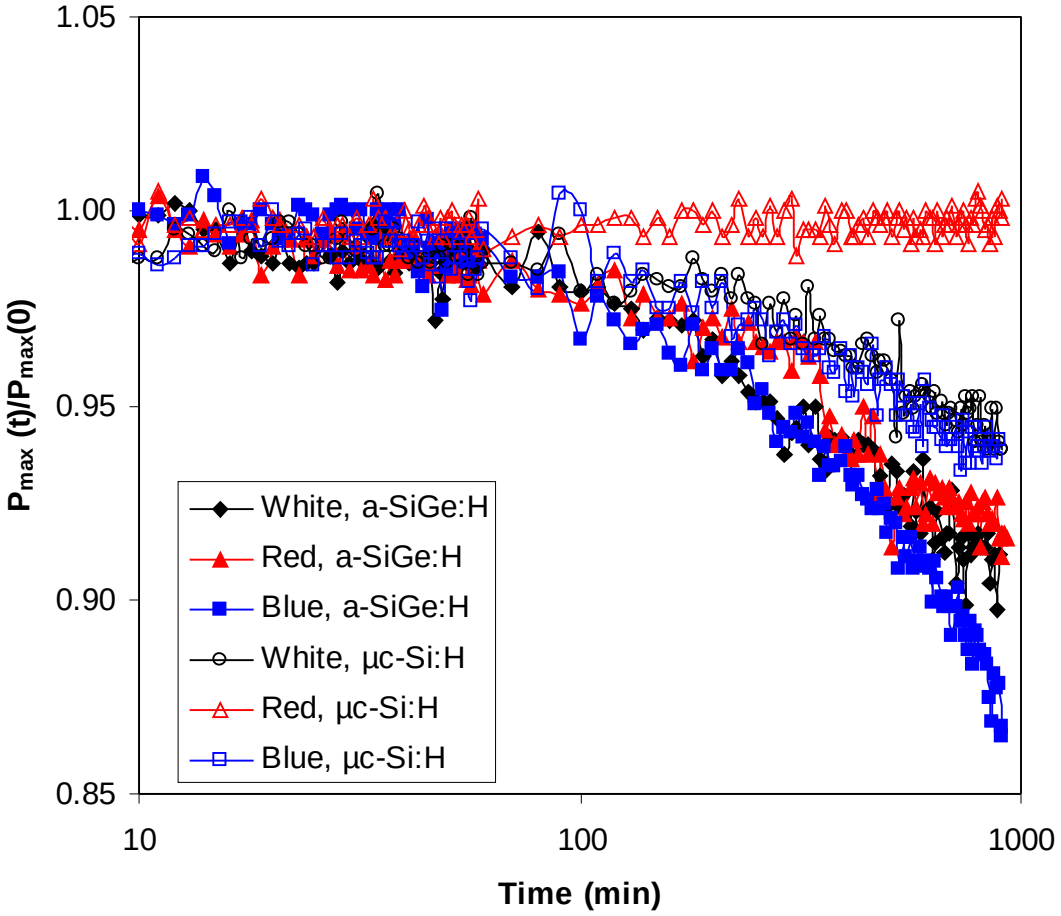
Light soaking under lights with different spectra



Light soaking under lights with different spectra

For nc-Si:H solar cell:

- No light-induced degradation was found under the red light.
- More degradation was under the blue light than under the white light, which is due to more absorption in the amorphous phase and more absorption near the *i/p* interface.

For a-SiGe:H solar cell:

- Light-induced degradation was observed under all three light sources.
- The blue light produced the highest degradation, the white light in the middle, the red light the lowest. The difference is mainly due to the non-uniform absorption.

Forward current soaking experiment

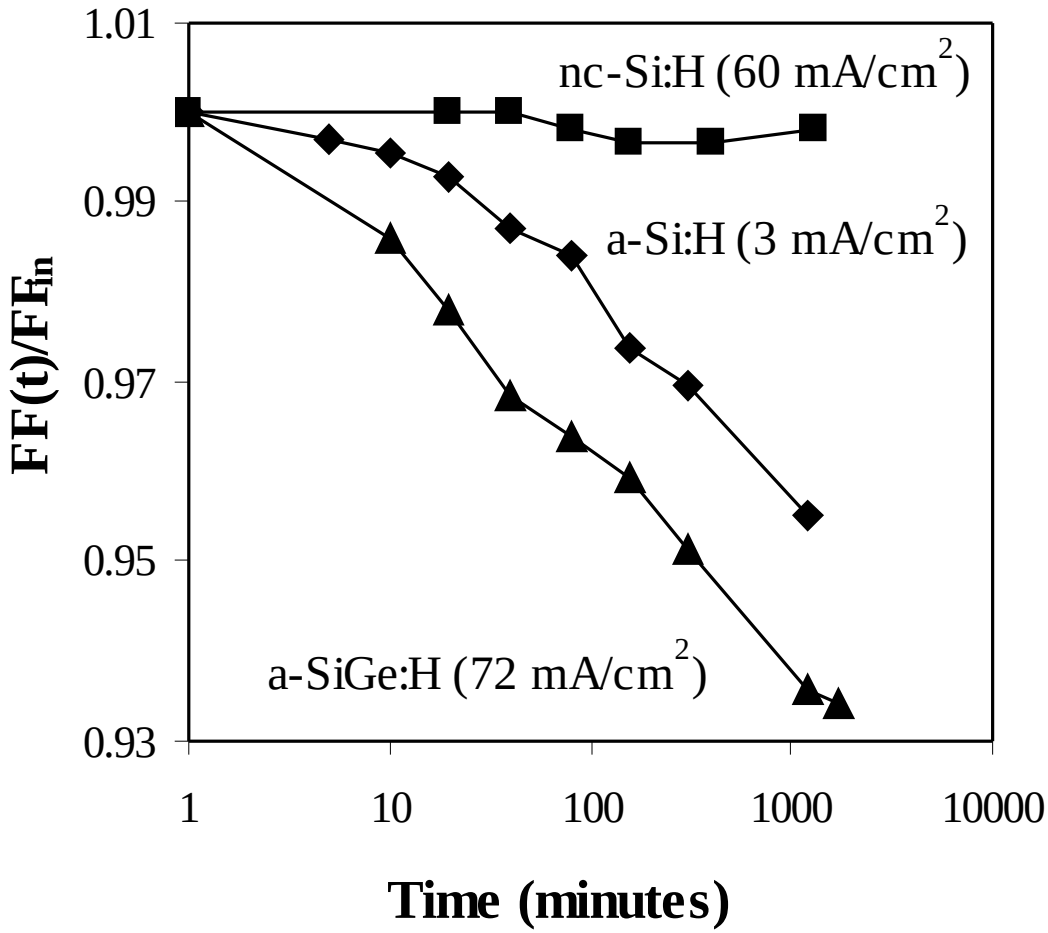


Table I. Behavior of V_{oc} and FF for an a-Si:H (Cell 1), an a-SiGe:H (Cell 2) and three nc-Si:H (Cells 3-5) cells under various forward bias conditions in the dark.

Sample	State	V_{oc} (V)	ΔV_{oc} (mV)	FF	$\Delta FF/FF_{in.}$ (%)
a-Si:H	Initial	0.998		0.696	
Cell 1	20 hr, 1V, 3 mA/cm^2	0.978	-20	0.664	-4.6
a-SiGe:H	Initial	0.623		0.638	
Cell 2	20 hr, 1V, 72 mA/cm^2	0.597	-26	0.596	-6.5
nc-Si:H	Initial	0.469		0.575	
Cell 3	15 hr, 0.5V, 7 mA/cm^2	0.469	0	0.579	+0.7
	Initial	0.469		0.591	
Cell 4	15 hr, 1V, 58 mA/cm^2	0.470	1	0.588	-0.5
	Initial	0.472		0.587	
Cell 5	64 hr, 1V, 57 mA/cm^2	0.474	2	0.590	+0.5

Light soaking under reverse electrical bias

Table II. V_{oc} and FF values for the a-Si:H (Cells 1, 2)and nc-Si:H (Cells 3, 4) cells before and after AM1.5 light soaking at 25 ^{o}C with and without a –2 V bias.

Sample	State	V_{oc} (V)	ΔV_{oc} (mV)	FF	$\Delta FF/FF_{in}$ (%)
a-Si:H	Initial	0.984		0.695	
Cell 1	69 hr, no bias	0.954	-30	0.635	-8.6
	Initial	0.985		0.704	
Cell 2	69 hr, -2 V	0.983	-2	0.708	+0.6
nc-Si:H	Initial	0.476		0.591	
Cell 3	63 hr, no bias	0.467	-9	0.559	-5.4
	Initial	0.476		0.594	
Cell 4	63 hr, -2 V	0.427	-49	0.523	-12.0

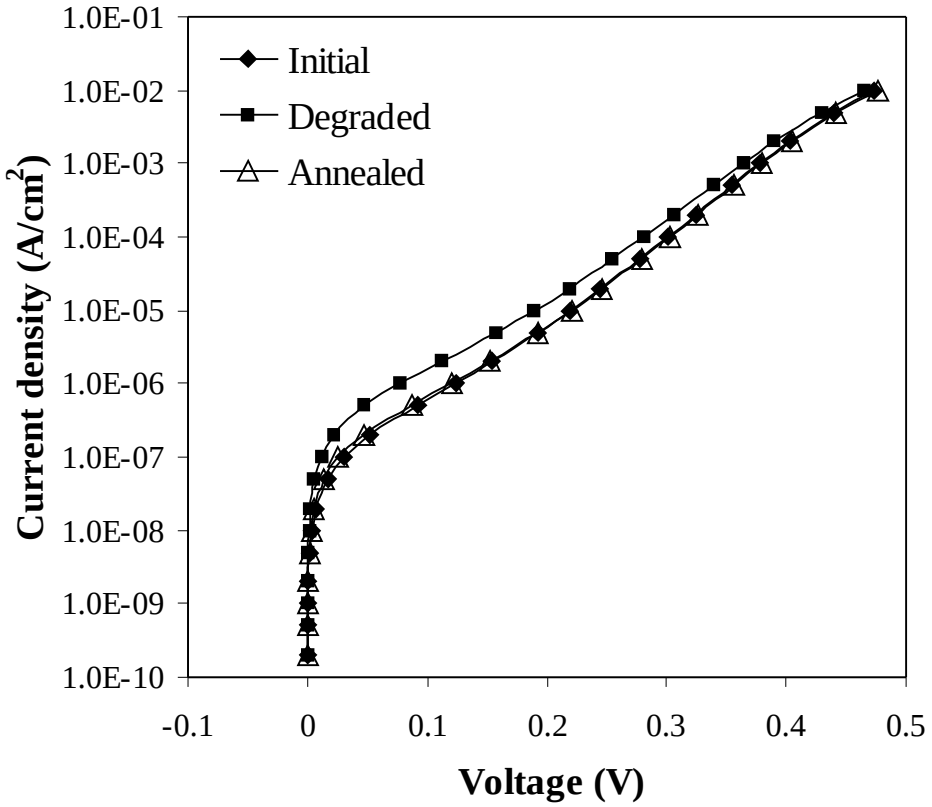
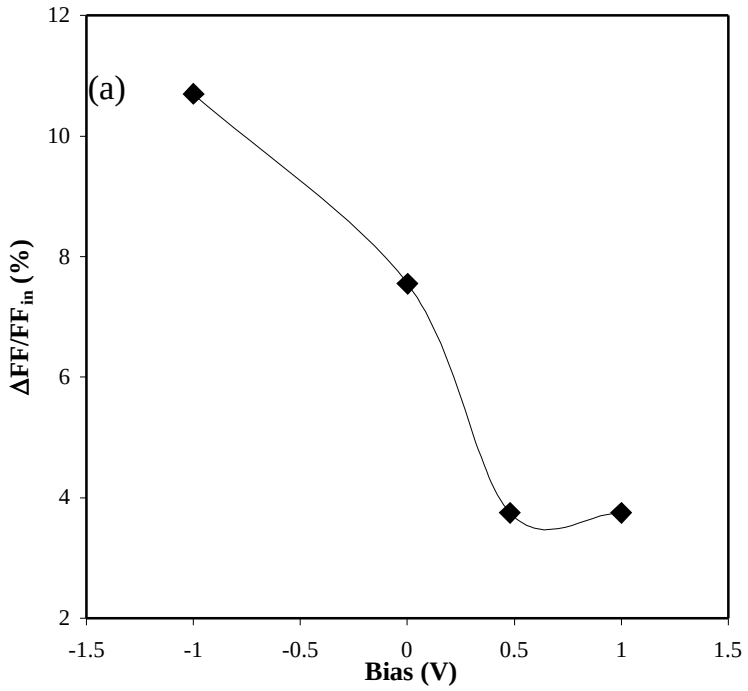
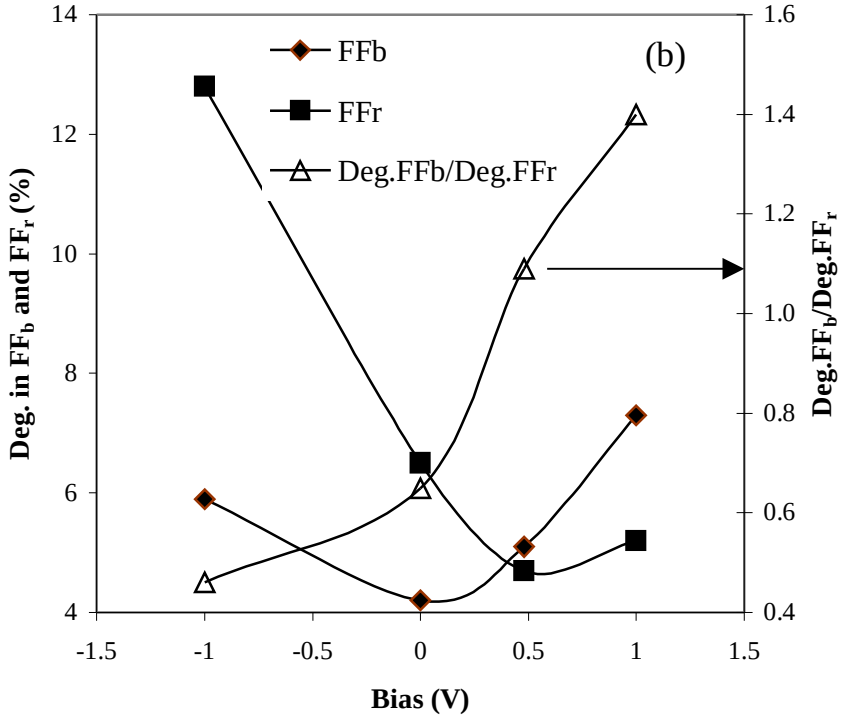

1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
Current density (A/cm2)
Initial
Degraded
Annealed
-0.1
0
0.1
0.2
0.3
0.4
0.5
Voltage (V)

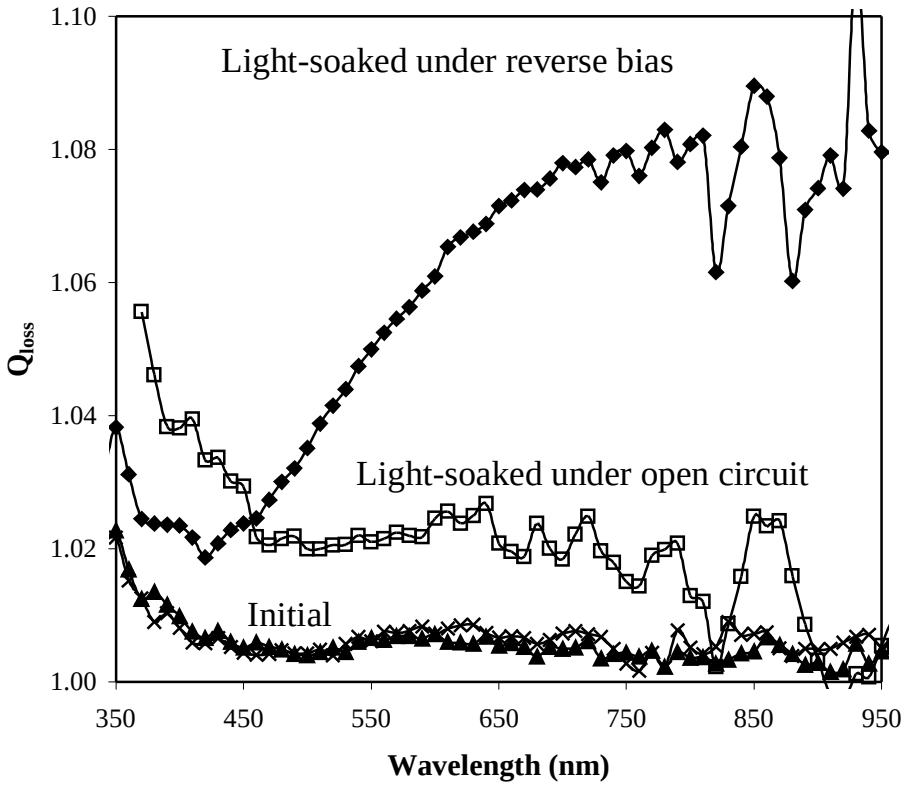
Table III. J-V characteristics of the initial (In.) and degraded (Deg.) nc-Si:H solar cells. The light-soaking was done under one sun white light with various bias conditions of –1 V, short circuit, open circuit, and +1 V at 50 ^{o}C.

Cell No.	Bias (V)	Status	V_{oc} (V)	ΔV_{oc} (mV)	FF	$\Delta FF/FF_{in}$ (%)	FF_b	$\Delta FF_b/FF_{bin}$ (%)	FF_r	$\Delta FF_r/FF_{rin}$ (%)
1	-1 V	In.	0.479		0.634		0.663		0.664	
		Deg.	0.464	-15	0.563	-11.2	0.624	-5.9	0.579	-12.8
2		In.	0.479		0.633		0.659		0.664	
		Deg.	0.464	-15	0.566	-10.6	0.624	-5.3	0.580	-12.7
3	Short circuit	In.	0.483		0.618		0.664		0.660	
		Deg.	0.472	-9	0.580	-6.1	0.636	-4.2	0.617	-6.5
4		In.	0.480		0.631		0.663		0.663	
		Deg.	0.474	-6	0.574	-9.0	0.638	-3.8	0.599	-9.7
5	Open circuit	In.	0.477		0.622		0.650		0.653	
		Deg.	0.470	-7	0.600	-3.5	0.617	-5.1	0.622	-4.7
6		In.	0.478		0.628		0.655		0.655	
		Deg.	0.470	-8	0.603	-4.0	0.618	-5.6	0.622	-5.0
7	+1 V	In.	0.482		0.608		0.655		0.655	
		Deg.	0.467	-15	0.587	-3.5	0.607	-7.3	0.621	-5.2
8		In.	0.478		0.629		0.656		0.651	
		Deg.	0.465	-13	0.604	-4.0	0.612	-6.7	0.624	-4.1

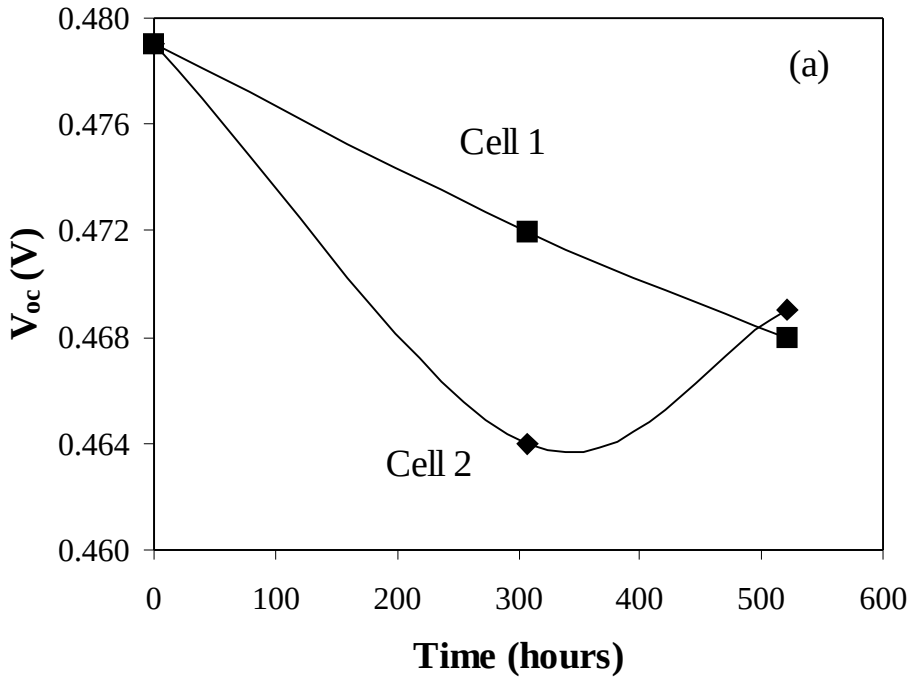




Light-induced changes as a function of electrical bias



Quantum efficiency loss (QE(-1V)/QE(0))of nc-Si:H solar cells after light soaking under various bias conditions



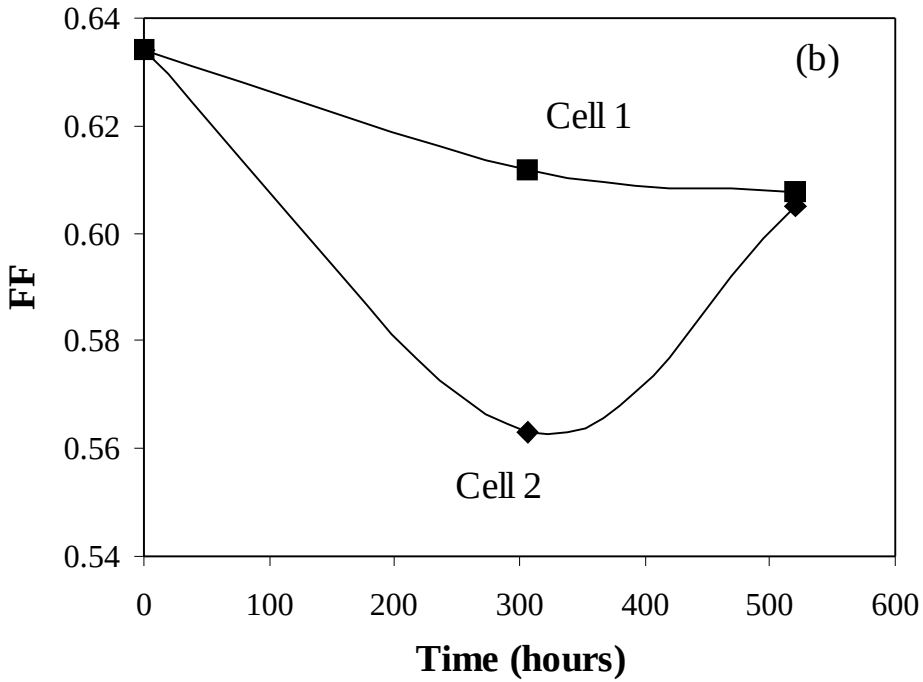


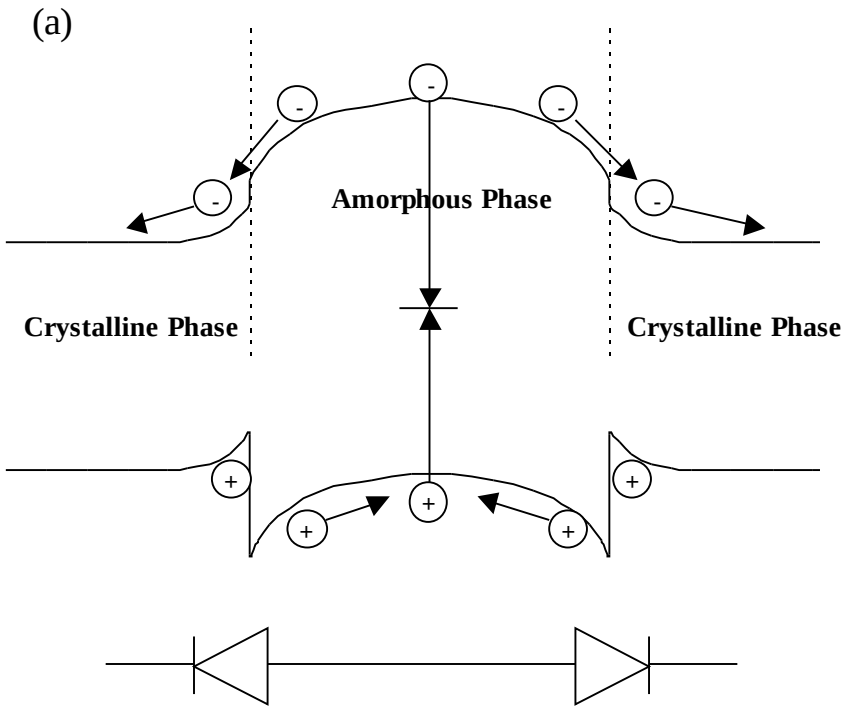
Photo-assisted annealing effect for the enhanced degradation by reverse bias.

Table IV. J-V characteristics of the nc-Si:H single junction solar cells before (In.) and after (Deg.) light-soaking with a reverse bias of –1.5 V at different light spectra. Light-soaking was carried out at 50°C for 309 hours. The intensity of the red, blue, and white lights was adjusted to produce the same short circuit current in the cells.

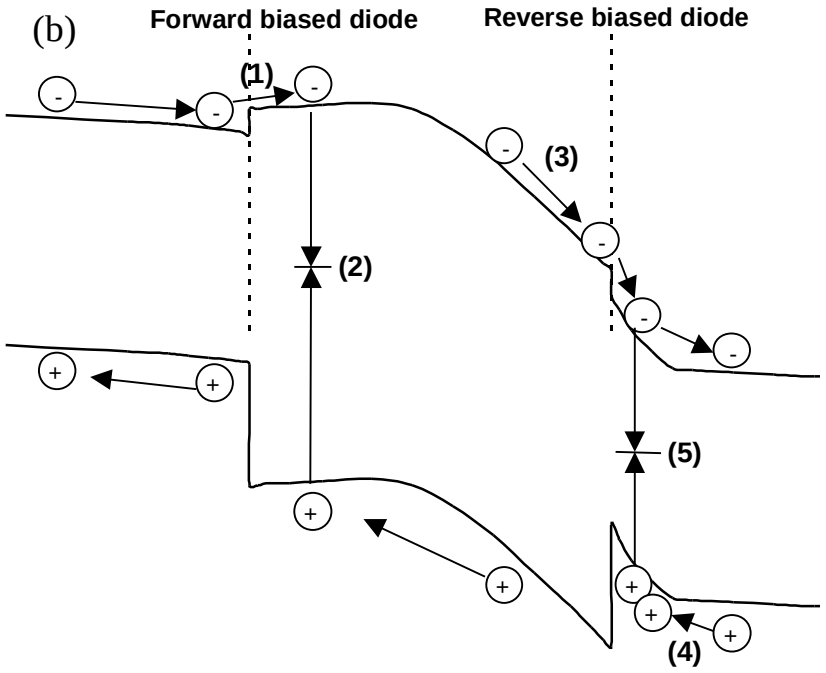
Cell No.	Light-soaking Conditions	Status	V_{oc} (V)	ΔV_{oc} (mV)	FF	$\Delta FF/FF_{in.}$ (%)
1	Red light	In.	0.472		0.593	
	-1.5 V	Deg.	0.472	0	0.598	+0.8
2	Blue light	In.	0.468		0.585	
	-1.5 V	Deg.	0.438	-30	0.539	-7.9
3	White light	In.	0.472		0.587	
	-1.5 V	Deg.	0.405	-67	0.527	-10.2

Summary of experimental results

1. Light-induced degradation was observed in nc-Si:H solar cells. The degradation is in the range of 0-15%.
2. Red light with photon energy less than the a-Si:H band gap does not cause degradation in nc-Si:H solar cells. Blue light causes more degradation than while light for the same light intensity.
3. No forward current induced degradation in nc-Si:H.
4. An electrically reverse bias enhances the light-induced degradation in nc-Si:H solar cells
5. The reverse bias enhanced degradation appears more for red than for blue light regions on the QE spectra.
6. The reverse base enhanced degradation can be partially recovered under open circuit condition.
7. Under a reverse bias, white light causes more degradation than blue light.



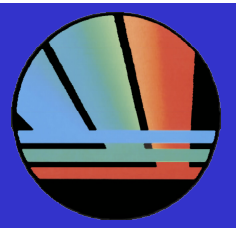
Band diagram for a crystalline/amorphous/crystalline region in nc-Si:H with zero average electric field



Band diagram for a crystalline/amorphous/crystalline region in nc-Si:H with an electric field.

Summary of the proposed model

1. Light-induced degradation is mainly in the amorphous and grain boundary regions
2. A crystalline/amorphous/crystalline region equivalent to a back-to-back diode structure
3. Reverse bias does two things: reduce the electric field in the forward biased diode and cause carries accumulation at the grain boundary region. Both mechanisms result in the reverse bias enhanced light-induced degradation
4. For an a-Si:H/nc-Si:H double-junction cells, the nc-Si:H mainly see the low energy photons and no light induced degradation expected.



Remaining fundamental questions:

1. **What determine the stability of nc-Si:H solar cells?**
2. **Are there more degradation for cells with high amorphous volume fraction?**
3. **Do light-induced changes occur in the amorphous phase or at grain boundary regions?**
4. **Are there any new defects generated after light soaking? What kind of defect?**

Thanks for the financial support from NREL and various technical supports from the team members